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A HISTORICAL SURVEY OF APPLICATIONS OF INFORMATION THEORY IN MUSIC

The principles of Information Theory as the statistics of information in communication was formulated during the late 1940s. Besides Thermodynamics and Communication Engineering (see Chapter 3), many applications in a diversity of disciplines have benefited from the possibilities Information Theory presents. Some of the most important applications include cybernetics, psychology, seismology, oceanography, automation, mathematical logic, neurophysiology, biochemistry, linguistics, computer science, economics, and artificial intelligence. In some applications, the theory is mainly used to establish models based on existing data, which in turn may be used to make intelligent predictions. Other applications use the theory for comparative studies in which specific instances may be compared with global possibilities.

For reasons expressed in the introduction and perhaps, because of the artistic association of music, it has had relatively little exposure to the methods of Information Theory, especially during the last 25 years. A degree of proficiency in mathematics and computers is obviously required, and because it means venturing into disciplines traditionally considered to be outside the realms of music, musicologists have been hesitant to make use of the possibilities it offers. Established methods of analysing music have for many years proven themselves quite adequate in many respects and alternative methods are perhaps not regarded as an urgent need.

Nevertheless, as shown in Chapter 1, music is also a mode of human communication which could benefit from the innovations and discoveries of modern technology. Many disciplines such as music therapy, marketing, broadcasting, and accelerated learning—fields that are not always directly related to music—apply music functionally. These applications often require music of a specific character or style that has shown to be suitable to that particular application. Conventional music analysis is rarely used to select music for these applications and most of the selection is done intuitively or by trial and error.

Traditional analytical methods, because of the familiar parameters they present, remain invaluable for the study of music and its properties, technically and artistically. Because of its technical orientation it is an important method by which the art of music making, interpretation, and composition can be understood and taught. Traditional methods usually allow for a large measure of flexibility of interpretation, and is suitable for what is sometimes referred to as 'fuzzy matching'.[1] In music this kind of imprecise comparison has proven to be very useful and through the years a complete technical vocabulary has been established which continues to expand. Yet, many of the terms used have a wide margin of meaning to allow diversity within a basic framework.[2]

The fact that analysts have resorted to general terminology to describe generic but diverse elements of music is an indication of the unpredictability of the art and therefore the creative forces that are at work. But although the traditional methods of analysis have an important role in the academic study of music, it is also often of a highly subjective nature which allows different analysts to arrive at different conclusions. However, by definition there is a difference between the technical features and the informational properties of music. If music is required for a specific application, that depends on its underlying communicative properties, a different approach or method is necessary to illustrate these properties.

Alternative methods of analysis are from time to time devised, many of which attempt to reduce the various structural levels of music to more manageable and concise values. The Schenkerian system of analysis is a good example of a system which, by reducing redundant elements, attempts to arrive at the underlying structure of a composition. In spite of the obvious merits of such new analysis methods and the fact that they are often recognised and accepted, they usually remain the domain of the specialists and are rarely accepted as part of the everyday study of music where the traditional methods remain firmly entrenched.

Progressive contribution to the knowledge about music very often comes from individuals who have less than a professional interest in music and whose field of specialisation is the technology which

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1 Fuzzy matching is part of the science of Artificial Intelligence and allows for the comparison of parameters which have a broad base of structural similarity in general without being identical. Musical form is a common example in which fuzzy matching is applied in music analysis; theoretically there are a relatively small number of prototypes (sonata form, binary form, ternary form, and rondo form) to which a large quantity of music may be compared.

2 In an attempt to be more precise, some authors invent adjectives which qualify specific musical procedures. Robert W. Ottman in his book *Elementary Harmony* (Prentice-Hall, 1983) uses the terms **Perfect authentic** and **Imperfect authentic cadence**, depending on the chord inversions and voice leading. By using these terms he tries to pinpoint specific characteristic features of cadences which would otherwise resort under the generic term Perfect cadence.

they use in the development of their new theories and techniques. This situation also applies to the research of the application of Information Theory to music which, to date, has mainly been done by researchers who, although specialists in communication technology or statistics, often have no more than a basic technical knowledge and a love for music.

Most of the important research done to date by researchers is, with some exception, limited to specific aspects of music. Usually the aspects that are musically most obvious such as rhythm and pitch are singled out for analytical treatment with Information Theory. There are some researchers, however, who have ventured into more complex analyses but who, during the early years, were still hampered by technological limitations. In the Introduction (Chapter 1) it was pointed out that very little research has been done or at least was published since the 1970s. It seems that the ascendance of powerful personal computers and the possibilities they offer drew much of the attention of researchers away from the analytical possibilities. This is shown by the tremendous amount that has been published about computer applications in music during the last twenty years, much of which is devoted to methods of representing information of music in computer languages. The remainder of this chapter is a synoptic overview of researchers and their work on Information Theory applied to music.

4.1 Music analysis by means of information theory

An early reference to the possibility that Information Theory could be applied to music appeared in 1946 or 1949[3] when Shannon and Weaver published in their book, *The Mathematical Theory of Communication*. Although their treatise was not directly concerned with music the authors inferred the possible application of Information Theory to music when they stated that:

> When we have an information source which is producing a message by successively selecting discreet symbols (letters, words, musical notes, spots of a certain size, etc.) the probability of choice of the various symbols at one stage of the process being dependent on the previous choices (i.e. a Markoff process), what about the information associated with this procedure? The quantity which uniquely meets the natural requirements that one sets up for 'information' turns out to be exactly that which is known in thermodynamics as **entropy**. (Shannon & Weaver: 1968, p.12)

Shannon only mentions music incidentally as a source of information and continues to describe the manner in which the principles of Information Theory are applied to information sources in general.

Nearly ten years passed before the validity of Shannon and Weaver's comments were realised. Although not addressing Information Theory as such, an important study of music as a communication medium and information source was done in 1956 by Leonard B. Meyer in *Emotion and Meaning in Music*. Approaching the subject from a psychological point of view, Meyer expresses the opinion that

[3] There seems to be disparity about the date of this publication and according to the sources consulted the date of publication of this book varies between 1946 to 1962. The edition of Shannon and Weavers book used for this research is dated 1968 and is probably a reprint. A further reprint may be found in a collection of their most important papers on information theory, edited by David Slepian in *Key Papers in the Development of Information Theory*, IEEE Press, 1973.

musical style is part of a predictability pattern which becomes internalised and on which textbooks are subsequently based. (Meyer 1956: Chapters 1 and 2) He links emotional expectation to musical experience without venturing further into the province of information content as such. Not only did Meyer himself use many of the ideas contained in his book as basis for further research in Information Theory, but a number of subsequent researchers took note of his ideas.

The first reports about actual analytical studies with Information Theory also appeared during the 1950s. 'Information Theory and Melody' is the title of an article by Richard Pinkerton published in *Scientific American.* (1956, pp. 77-87) Pinkerton's research consisted of counting the pitches of thirty-nine nursery melodies to obtain certain values which he subsequently used as a model to create melodies of his own. The method he applied to compose the melodies is discussed in the second half of this chapter.

Meyer continued his discourse a year later with an article, 'Meaning in Music and Information Theory', in the *Journal of Aesthetics and Art Criticism.* (1957, p. 412-424) In this article Meyer links 'meaning' in music with the information content of music. He refers to his book mentioned above (*Emotion and Meaning in Music*), when he says:

> In that [book's] analysis of musical experience many concepts were developed and suggestions made for which I subsequently found striking parallels indeed equivalents in information theory. Among these were the importance of uncertainty in musical communication, the probabilistic nature of musical style, and the operation in musical experience of what I have since learned to be the Markoff process. (Meyer: 1957, p. 412)

In essence, Meyer's article deals with the correlation of musical meaning, value and information and arrives at the conclusion that these three elements are different but

> ... related experiential realisations of a basic stochastic process governed by the law of entropy. (Meyer: 1957, p. 424)

Meyer did not do any analyses himself, and limited his discussion to the arguing of hypotheses and intuitive concepts. Some two years later, in 1958, Joseph E. Youngblood published the results of his musical analysis in an article with the title, 'Style as Information', in the *Journal of Music Theory* in which he also expresses the belief that Information Theory could be suitably used to identify musical style. (Youngblood: 1958, pp. 24-35)

Youngblood's analysis is tentative as he only works on the pitch distribution of various melodies by Schubert, Schumann and Mendelssohn as well as four Gregorian chants. Although his work is important from a historical point of view, he does confuse information generated by stylistic conventions at the source (the composer and the score) and information as received by the listener. In his discussion of maximum entropy of the chants he rationalises the use of both a base of twenty seven[4] as well as twelve notes:

> ...modern listeners are prepared to respond to twelve divisions of the octave, and consequently, maximum uncertainty is for them represented by log12 and not by log27. (Youngblood: 1958, p. 31)

The problem with Youngblood's viewpoint is that he ignores the fact that a composition should be regarded as a closed discrete system in which the total number of symbols contained in the message dictates the maximum amount of information (in this case uncertainty). This was discussed in Chapter 3 and is a basic premise stipulated by Hartley (see page 3-4). What a listener is ready to respond to[5] has very little bearing on the inherent style of a composition and the information it generates. Any limitation or freedom of choice a composer displays in his composition should be seen against the possible choices that are made available to him by convention, the system which serves as a frame of reference, and the actual limitation he consciously or unconsciously imposes on himself. Only a small portion of a very large range of possibilities available to the composer may be present in a specific composition and only those elements used by the composer represent the information content of the composition.

In the conclusion to his article Youngblood admits that other factors would have to be brought into consideration as well but confirms the validity of Information Theory as a method of stylistic analysis:

> Most musicians can at present either intuitively or on the basis of certain vague generalisations identify at least five or six historical styles. It seems, however, that it would be useful to find a means of identifying and quantifying the characteristic features of style, as well as measuring the differences between styles, if for no other reason than to provide a basis for understanding and evaluating contemporary music. (Youngblood: 1958, p. 31)

One of the most exhaustive and thorough books on information and the arts was published by Abraham Moles in 1958, under the title *Théorie de l'information et perception esthétique*.[6] Addressing aesthetic information of the arts in general, Moles heuristically explores the role and application of Information Theory to communication from the perceivers point of view. Chapters two and three refer extensively to Moles' research and conclusions. Following the publication of Moles' book, researchers on the subject were inspired by the ideas propagated by him and often rely extensively on definitions and descriptions contained in his book. It is unfortunate that the subject about which Moles wrote so thoroughly has not earnestly been pursued by other writers, and that his treatise which is now nearly 40 years old, remains one of the few extant works on this subject.

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4 It is not clear why Youngblood refers to 27 notes, neither does he provide any reason. If he refers to enharmonicism, the total number of notes theoretically available is 35 (5 accidentals multiplied by the 7 diatonic pitch names).

5 Youngblood's statement seems to be incorrect fundamentally, as he implies that listeners only respond to the twelve chromatic tones of Western music. He thereby implies that listeners would not respond to quarter tones or smaller intervals.

6 Translated from French into English in 1965 by Joel E. Cohen as *Information Theory and Esthetic Perception* (University of Illinois Press).

'Information as a Measure of Structure in Music', is the title of an article by Edgar Coons and David Kraehenbuehl which was also published in a 1958 edition of the *Journal of Music Theory.* (1958: pp. 127 -161) Their approach is somewhat different to that of Youngblood in that they calculate the information of musical form in relation to human expectation with the general aim of finding a connection between musical and non-musical symbols:

> Once the facts regarding the nature of pattern can be stated rigorously, it will become possible to develop a general theory of formal process in music. Since information is a measure of formal effectiveness that is independent of the specific nature of the elements composing the pattern, exact structural comparisons between musical and non-musical experiences will become feasible, paving the way to a sound theory of the symbolic processes in music. It seems reasonable to assume that the musical symbol and the reality it symbolizes have in common nothing more than their structural properties. (Coons & Kraehenbuehl: 1958, p.151)

Although hypothetically correct, Coons and Kraehenbuehl's theory is no more than just that; in music repetitions are seldom identical (except when music is repeated by means of repeat signs). According to traditional methods of structural analysis, slight variations in musical repetition will have little effect on the final structure. Information Theory on the other hand will identify such variations as being different rather than mere repeats.

Various scholars, stimulated by the challenges the new research in Information Theory presented, became involved in the science and presented their findings – usually of a tentative nature – in journal articles. Analysis with Information Theory, mainly on the rhythmical contents of melodies, was done by John Brawley in 1959 as part of research towards a Master's thesis at the University of Indiana, while a more general approach was taken by Joel Cohen in 'Information Theory in Music'. (Cohen: 1962, pp. 137-162)

However, the most important research during the 1950's and 1960's was done by Lejaren Hiller who contributed a number of articles and a book in the following years up to 1967. Hiller's main interest was in the application of Information Theory in composing music, which is treated at greater length later in this chapter. His book, *Information Theory and Musical Analysis*, (1962) is the first extensive work to elaborate on the application of the theory to music. In co-operation with Calvert Bean an analysis of four sonata expositions was done and the results published in the *Journal of Music Theory.* (Hiller & Bean: 1966, pp. 96-137)

A year later, in 1967, Hiller and Ramon Fuller published the results of an analysis of Webern's symphony op. 21, also in the *Journal of Music.* (Hiller & Fuller 1967: pp. 60 -115) This work by Hiller and Fuller is significant because conventional analysis is compared and combined with Information Theory analysis in an attempt to show how the two may complement each other. Part of the contents of this article is based on Fuller's thesis for a Doctorate of Musical Arts at the University of Illinois, *An Information Theory Analysis of Anton Webern's Symphonie*, Op. 21. (unpublished: 1965)

The conventional analysis of Hiller and Fuller's is straightforward and deals mainly with the pitch structure of the various appearances and transpositions of tone rows, the canonic structure, instrumentation, and rhythm. The entropy analysis is more extensive, in fact one of the most comprehensive until then. Four dimensions of entropy analysis are included: pitch, four different types of interval relationships, rhythm, and pitch and rhythmic combinations. The results of their computations are recorded on a large number of graphs.

In 1964 analytical research on Karnatic music was done by Gift Siromoney and K. R. Rajagopalan and the results published in an article with the title, 'Style as Information in Karnatic Music'. (Siromoney & Rajagopalan 1964: pp. 267-272) Applying similar criteria as Youngblood, Siromoney and Rajagopalan also limited their analysis to the counting of pitches. This analysis could have shown some interesting results because Karnatic music is based on a completely different tuning system than that of Western music and provides for seven *svaras* and twenty-two *sruthis* to the octave with a maximum entropy of 2.807 bits and 4.459 bits respectively.

For no apparent reason the two researchers limited the number of notes:

> In this paper, we shall however represent the notes of the Karnatic system by their nearest notes in the Western scale. (Siromoney & Rajagopalan: 1964, p. 268)

The calculations are further incomplete because the particular scales peculiar to each *raga* type were not taken into account.

In 1966, L. A. Hiller and C. Bean attempted to solve problems of the analysis of musical structures by applying Information Theory to subdivisions of larger sections. (Hiller & Bean: 1966, pp. 60-115) The results of their investigation was published in the *Journal of Music Theory*, under the title 'Information Theory and Analyses of four Sonata Expositions'.

These studies mainly have in common the fact that they have either concentrated on the frequency of individual pitches or on rhythm only, and that pitch relationships and interval relationships were ignored. Establishing pitch frequencies is important in musical analysis with Information Theory in order to obtain an idea of note distribution, but to base an entire analysis only on this aspect of music without regard for any other, contributes little to the analysis of musical style. Pitch names by themselves merely outline intervals. Musical activity is largely dependent on the movement of intervals. The characteristics of a melody is therefore dependent on its intervallic structure and not the pitch names.

Some of the problems that Information Theory presents in the stylistic analysis of music were investigated in 1971 by Norman Dale Hessert in a dissertation towards a D. Phil. degree, *The Use of Information Theory in Musical Analysis*. He confirms that pitch frequencies are less valid by themselves and believes that interval relationships are more important:

> 1. Using twelve melodic intervals from the unison through the major 7th makes possible a standard alphabet by which to analyse melodies of any style period.
>
> 2. Analysing the interval content of a melody avoids the problems of determining tonal centres and exact points of modulation.
>
> 3. Intervals more clearly reflect the elements of redundancy and entropy (unity and variety) than do scale degrees. For example, using the scale as basis of analysis, the repetition of a motive at a different pitch level is reflected in the numerical results as an element of variety rather than unity.
>
> 4. Analysis at the level of first-order transition probabilities (single notes) is probably not very meaningful. It would be easy to show that two melodies which are dissimilar in style can have the same pitch content. (Hessert: 1971, p. 44)

Thus far most of the analytical research has tended to be inconclusive for the following reasons:

1. Much of the research has concentrated on a single dimension of music such as melodic pitches, rhythm or form. Musical style is multifaceted and a single element can only represent one such facet.

2. Even where multidimensional analysis was done, some researchers have tried to express the results of the analysis as a single numerical figure, instead as a model of multiple figures, of which each figure would represent one of the aspects of musical style.

3. The Markov Process (see Chapter 2), which is important for the indication of the tonal and structural coherency of musical style, has rarely been applied consistently. This has resulted in a simplistic application of Information Theory.

4. The representation of entropy values purely as numbers usually does not allow for a clear overview of the results and therefore could tend to be meaningless and unfamiliar to many musicologists.

Hessert concludes his Ph.D. dissertation with the comment that ...

> Certainly no application of information theory has thus far been able to reflect either the existence or the effects of the Markov process in its numerical results. And, since it is the Markov process which is the basis of this particular theory of messages and communication, it would seem that those who have worked in this area have been unsuccessful in obtaining any really meaningful results in their application of information theory to the analysis of music. (Hessert: 1971, p. 85)

Hessert's criticism is concerned with the way Information Theory had been applied and not with the theory itself. In fact, he specifically refers to the simplistic application of Information Theory to single aspects of music, often with disregard for the interrelationships which exist, not only between the various aspects, but also between smaller and larger elements of specific aspects. In all fairness it should be added that most of the researchers who have laid the foundations of Information Theory and music were not musicians themselves which may be why they mainly concerned themselves with the most obvious musical elements; melody and rhythm. Musicians who venture into research with Information Theory usually did not have access to the technological resources that their colleagues in the Communications sciences had, and which was a restricting factor on the extent of their work.

Not only has the value of Information Theory been recognised as an analytical tool, there were also a number of composers — professional and amateurs — who realised that Information Theory could be applied to the compositional process. The next section discusses some of aspects of composing with the help of the principles of Information Theory.

4.2 Music compositions based on information theory

Although composition is not the subject of this research some of the techniques used by the composers mentioned here address some of the arguments that are discussed. Composers have applied a variety of principles and methods of Information Theory to create their music that tend to support some the arguments that are expounded in this dissertation. Because of this some of the more important composers and their works as well as the principles they applied are discussed here.

Since the 1950s when computers and electronic musical instruments began their fast rise to general application, a number of composers have been working towards emulating the processes of musical compositions by using electronic equipment. Artificial intelligence, of which Information Theory is an important feature, has become an important element in composing music with the aid of computers. Artificial intelligence attempts to emulate human thought processes but requires that large amounts of information be programmed into a database which the program has access to. The information referred to here is synonymous with the ‘rules’ or parameters which need to be applied to sound in order to create acceptable music. Because computers are very effective for the manipulation of numbers, the application of Information Theory, which translates conventions into number values, may serve as an excellent vehicle for ‘musical rules’ to create music with computers.

Music composed with the aid of computers can play an important role in attempts to discover the factors that make up musical style. An artificial computer composition based on synthesised information may be compared with music composed by humans to give an indication of those elements which are required in the original computer programmes. Stochastic principles offer a method by which composers of computerised music may incorporate parameters into their compositions.

Pierce and Shannon were among the first researchers to compose music with the help of a computer which was programmed with information obtained with Information Theory. In 1949, they completed a chorale-like piece of music by selecting diatonic chords from a preconceived list of chords. However, the music they created was not yet totally generated by the computer. Besides the list of chords, they also manually manipulated the phrase structures and cadences. A rule which they included in the parameters was that each subsequent chord should have a note in common with the preceding chord and in the same voice (Pierce & Shannon: 1949) — an example of the stochastic principle at work.

The results were stylistically not very 'human' as is evident from Hessert's commentary:

> The weaknesses of the composition... are many — the use of second inversion triads, the three consecutive ascending melodic fourths, the impossibility of root movement by second (sic) — but, in terms of information theory, the problems are that the probabilities for the occurrence of the individual chords are not taken into consideration and that the Markoff chain is not part of the compositional process. (Hessert: 1971, p. 88)

Hessert's observations concern the absence of common musical conventions which could have been resolved by including additional information in the generating programme. His criticism is therefore mainly based on his expectancy of a certain style of music in which certain conventions may be found. There was, in other words, too much entropy or information present in the composition generated by Pierce and Shannon to satisfy Hessert's preference. It is revealing that Hessert's objections are subjectively based on well known traditions and conventions. This is an important observation as far as this research is concerned, since he compares a composition which had been composed according to its own inherent criteria to musical style of his own personal preference. This seems to support the argument that Information Theory is able to extract and make prominent those elements that are regarded as preferential or necessary for a specific purpose. Pierce and Shannon's music has a high entropy value with the result that it is too unpredictable to fit within a preconceived style of music. The parameters which they included in their composition are, in other words, too sparse to create music of a recognisable style.

Some composers prefer to apply the principles of Information Theory without attempting to incorporate traditional conventions. Important work in this respect was done by Iannis Xenakis whose composition, *Metastasis* (1953-1954) was created according to stochastic principles. In an article of 1966, *The Origins of Stochastic Music*,[7] Xenakis, who is also a mathematician, explains that the creation of, what he calls probabilistic music in the twentieth century, was a natural outflow of serialism:

> ... in 1954 a music constructed from the principles of indetermination was developed from, amongst other things, the impasse of serial music; two years later I baptized this music 'musique stochastique'. It was as a musical necessity that the laws pertaining to the calculation of probabilities found their way into composition. (Xenakis: 1966, p.12)

Although Xenakis refers to indetermination in the quotation above, his application of stochastic principles, in reality implies a method of composition in which indetermination is controlled by basic predetermined factors. In fact his reference to the 'calculation of probabilities' confirms that he uses basic 'rules' within which indetermination is allowed to work. The basic techniques and theories on which

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7 This is a translated and abridged version of the French article, 'Les musiques formelles', which was published in *Revue Musicale* (no. 253-254:1966). The translator is G.S.N. Hopkins.

Xenakis based his compositions are contained in a series of articles and essays which appeared in a variety of French and German journals and a book published between 1955 and 1968.[8]

Further experiments with musical compositions generated by means of Information Theory, but in which the Markov chain features to some extent were done by David Slepian in 1951 and Richard Pinkerton some five years later.

Slepian's technique consisted of letting a colleague listen to the first portion of a bar of music. The colleague was then required to complete the bar. A second colleague listened to the portion completed by the previous colleague, and so on until the composition was considered complete. By applying this method Slepian ensured that each portion of music was always connected to what preceded it.

Pinkerton's approach differed radically and was based on the analysis of a group of nursery melodies according to the methods of Information Theory. He calculated the first and second transition probabilities (orders) for the seven notes of the diatonic scale plus an additional symbol which represented the rest or lengthened note. Using this information in a binary framework in which some notes had to be followed by others while other notes were followed by a choice of two notes, Pinkerton was able to conceive elementary melodies.

The most successful composition which incorporated stochastic principles was the *Illiac Suite* for String Quartet by L. A. Hiller and L. M. Isaacson.[9] Composed in 1957 with help of a computer which was programmed with compositional rules and selections based on the Monte Carlo technique.[10] Hiller and Isaacson's technique was rather complex and they based the suite on a combination of Hindemith's interval sequence (Series I) and that particular interval's distance from the unison (proximity value).

The numerical values they obtained are shown in Table 4-1 and were manipulated in a variety of ways to obtain different results and to ultimately generate the suite. 'Stylistic' variation in the *Illiac Suite* was achieved by increasing and decreasing the entropy value of the individual notes in relation to the whole.

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8 The journals referred to here include *Gravesaner Blätter* (1955-1965), *La Nef* (1967), and *Revue d'Esthètique* {1968). The book from which certain portions were used is *Musiques Formelles* (Richard Masse, 1963).

9 A copy of the 'Illiac suite' was reprinted with corrections in the authors' publication, *Experimental Music*, (1959, pp. 182-197).

10 The Monte Carlo technique is based on the laws of chance by which choices are made from sets of random numbers and made to conform to statistical controls.

Interval	Interval number	Hindemith Series I	Proximity value	Combined value
	V	X	Y	Z=X+Y
Unison	0	13	13	26
Octave	12	12	1	13
Fifth	7	11	6	17
Fourth	5	10	8	18
Maj 3rd	4	9	9	18
Min 6th	8	8	5	13
Min 3rd	3	7	10	17
Maj 6th	9	6	4	10
Maj 2nd	2	5	11	16
Min 7th	10	4	3	7
Min 2nd	1	3	12	15
Maj 7th	11	2	2	4
Tritone	6	1	7	8

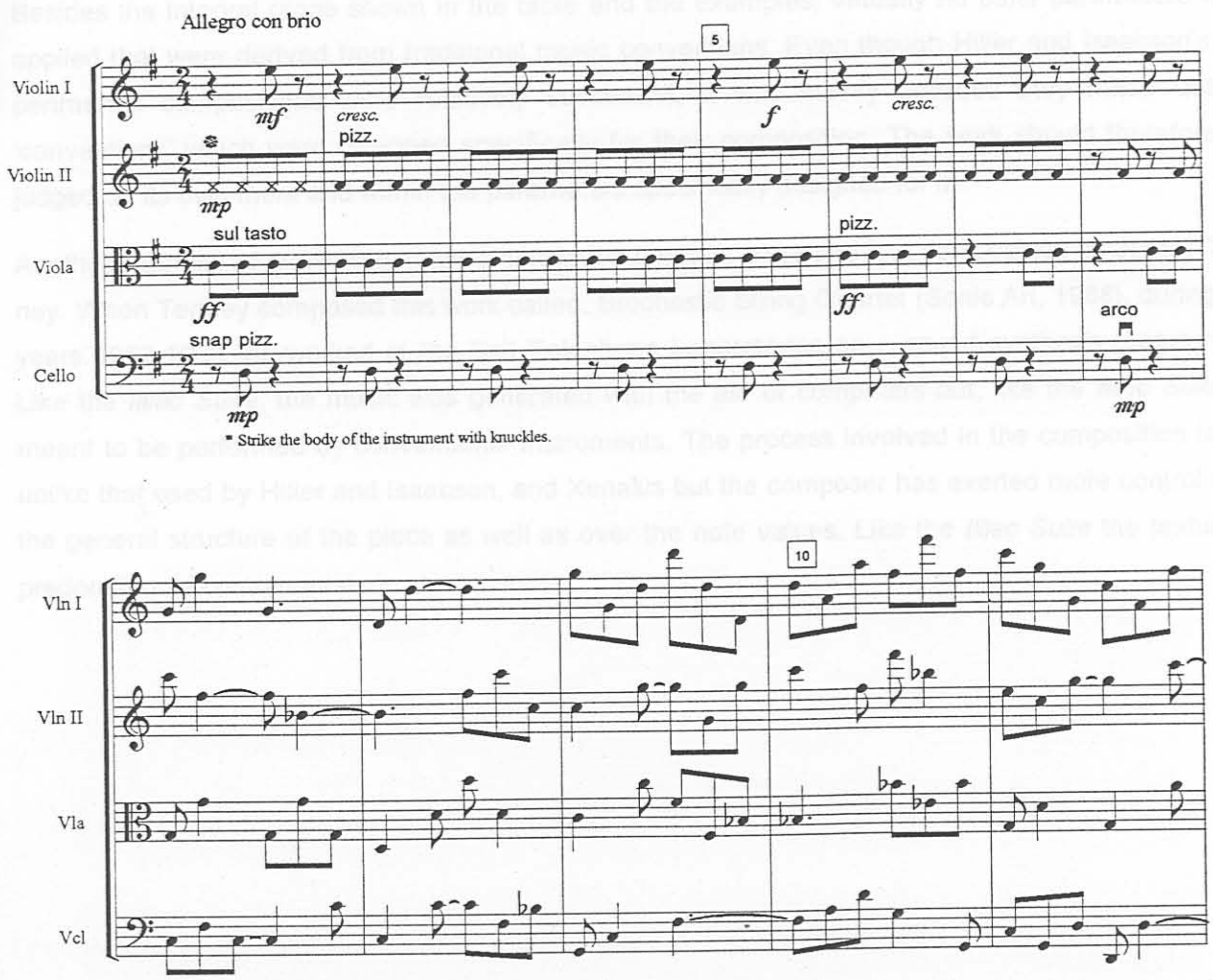
Table 4-1. Calculation of the note values for the *Illiac Suite* by L. A. Hiller and L. M. Isaacson

The following examples are extracts of the four movements or 'experiments', as the composers referred to them. A comparison of the first number of bars of each movement gives an idea of the degree of variation that the composers managed to achieve by using the basic range of notes shown in the table together with a varied manipulation of the stochastic processes.

Example 4-1. *Illiac Suite*: Experiment I, L. A. Hiller and L. M. Isaacson

Example 4-2. *Illiac Suite*: Experiment II, L. A. Hiller and L. M. Isaacson

Example 4-3. ***Illiac Suite*: Experiment III, L. A. Hiller and L. M. Isaacson**



Example 4-4. *Illiac Suite*: Experiment IV, L. A. Hiller and L. M. Isaacson

Besides the interval range shown in the table and the examples, virtually no other parameters were applied that were derived from traditional music conventions. Even though Hiller and Isaacson's experimental compositions were relatively successful, it was mainly because they made use of 'conventions' which were designed specifically for their composition. The work should therefore be judged on its own merit and within the parameters specifically designed for it.

Another example of stochastic music is shown on the next page and is a composition by James Tenney. When Tenney composed this work called, Stochastic String Quartet (Sonic Art, 1988), during the years 1962-1963, he worked at the Bell Telephone Laboratories on a sound synthesis programme. Like the *Illiac Suite*, the music was generated with the aid of computers but, like the *Illiac Suite*, is meant to be performed by conventional instruments. The process involved in the composition is not unlike that used by Hiller and Isaacson, and Xenakis but the composer has exerted more control over the general structure of the piece as well as over the note values. Like the *Illiac Suite* the texture is predominantly contrapuntal.

Example 4-5. Stochastic String Quartet, James Tenney

4.3 Conclusion

Some of the research applications in music that has been done since the formulation of Information Theory, were mentioned in this chapter. Little of this research has resulted in any dramatic changes in the approach to music analysis, neither has it had any marked affect on the traditional methods of music analysis. Investigation of this science has shown that although many other disciplines have benefited from the principles of Information Theory, little progress has been made in its application to music during the last two decades. Some of the applications have had an indispensable and far reaching influence on the development of technology, to such an extent that Information Theory has become an important branch of the science of statistics.

Besides the analyses of music that has been described in this chapter, other applications are mainly limited to composition in which a number of composers have used various aspects of Information Theory.